The hydroacoustic network is a key component of the International Monitoring System (IMS). The network contains 11 stations to monitor compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) in the world’s oceans. This is a relatively small number compared to the components that make up the other IMS networks, which include 50 primary and 120 auxiliary seismic stations, 60 infrasound, and 80 radionuclide stations. This is because the Sound Fixing and Ranging channel (SOFAR), the natural ocean acoustic channel, enables underwater sound to propagate over large distances without significant loss. It is thus possible to record underwater signals at hydroacoustic stations several thousand kilometres away from the source, provided the propagation path is not blocked by a land mass.

The network’s six hydrophone stations consist of triplets of receivers placed in the middle of the SOFAR channel. Each receiver triplet comprises three hydrophones which are arranged in triangles with each point set two kilometres apart (see page 17). This setup leads to a resolution in direction. The location of an event can then be determined by identifying the intersection of bearings received from any two remote stations. Each station is linked to the shore via a cable, which allows for ocean acoustic data to be processed in real time. The other five IMS hydroacoustic stations are island-based “T-stations” and use seismometers to detect the high frequency seismic waves converted from hydroacoustic waves when they hit the island.

The hydroacoustic network is of particular significance for coverage of the southern hemisphere, which has immense ocean areas compared to the northern hemisphere with its large landmasses. Placed within the world’s three major oceans (the Atlantic, Pacific, and Indian Oceans, which make up about 70 percent of “the surface area” of the Earth) this network has the capability to detect in-water, on-island or low-altitude explosions over water.

In-water explosions contain low and high frequency energy, have a short duration and normally display a bubble pulse. The signature of explosions on islands differs somewhat. Depending on the size and/or location of the explosion on the island, the signals contain less high frequency energy and no bubble pulse (see Figure 1). For low altitude explosions over the water, low frequency hydroacoustic signals of a short duration have been observed.

---

**EXAMPLES FOR SYSTEM PERFORMANCE & SYSTEM IMPROVEMENTS OF THE HYDROACOUSTIC NETWORK**

In the case of the IMS seismic network, the performance of the International Data Centre (IDC) can be compared with earthquake information centres around the globe, for example, the National Earthquake Information Center (NEIC) run by United States Geological Survey (USGS) or the International Seismological Centre (ISC).

The situation is quite different for the IMS hydroacoustic network. Other similar networks with freely accessible data do not exist. Furthermore, there are hardly any historical records available of large nuclear in-water explosions recorded on hydrophones, whereas there are many examples of nuclear tests recorded on seismometers. Therefore, determining the capabilities of the hydroacoustic network is based on an analysis of signals received for events with known location, depth and yield. This “ground truth” information for observed events is often not available.

To overcome this problem, well documented, controlled non-nuclear underwater test-explosions are the most suitable means for performing an evaluation of the hydroacoustic network including data processing, since precise “ground truth” data like location, depth and yield of the explosion are then known. However, carrying out these kinds of tests is costly and permits are difficult to obtain. Finding a means to conduct more tests would be of great benefit to the development of the network.

Through cooperation with research institutes during the implementation of the International Scientific Studies project over the past year,
the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) received information about a couple of hydroacoustic in-water events, including “ground truth” data. These events demonstrated the potential of the existing IMS hydroacoustic network in terms of sensitivity and location accuracy: on 7 and 8 September 2008, a series of low-yield explosions (estimated 20 kg TNT equivalent) on the continental shelf off the coast of Japan were detected 16,000 km across the Pacific Ocean by hydrophone triplets belonging to IMS hydroacoustic stations H03 (Juan Fernandez Island) off the coast of Chile (see Figure 4). This provides substantive evidence of the long-range detection capability of the hydroacoustic network.

The detection of these low-yield explosions clearly illustrates the ability of the sparse, global hydroacoustic network to cover the three major world oceans.

On 2 August 2006, the battery pack of a mooring of oceanographic equipment accidentally exploded off the coast of New Jersey, United States. This incident was recorded by H10 (Ascension Island) in the Atlantic Ocean (see Figure 4) at a distance of about 8000 km. The provision of “ground truth” time and location data for this event enabled the CTBTO to estimate location uncertainties in this region.

After signal processing, the observed direction of signal arrival and the real direction of the event based on its known location differed by less than 0.2 degrees. The observed travel time also agreed with the IDC-predicted travel time to within two seconds.

Although these examples are useful, carrying out comprehensive studies on a global scale will require a greater number of either controlled underwater test explosions or in-water events with sufficient “ground truth”. This will take time and can only develop gradually.

During the ISS Conference (ISS09), scientists from the Curtin University of Technology in Australia presented results of their studies of transient low-frequency hydroacoustic signals in the Indian Ocean observed at IMS hydroacoustic stations H01 (Cape Leeuwin) in Western Australia and H08 (Diego Garcia) in the Chagos Archipelago, Indian Ocean (see Figure 4). Signals generated by ice rifting events on the ice shelves and iceberg calving from regions along the Antarctic coast, about 3300 km away from Australia, are of special interest to them. The temporal variations in the frequency of occurrence of such events along the coast of Antarctica reveal a noticeable seasonal component and have been related to environmental effects like climatic trends for Antarctica by this group.

Figure 1
Comparison of a sonogram (intensity versus time and frequency) of a nuclear explosion in the basement of the island Mururoa, 27 October 1995 (left) and a seaquake close to Japan (right), Peter Wille, Sound Images of the Ocean, Springer 2005, and reference therein.
In particular, the Curtin University researchers studied the accuracy of observed directions of signal arrivals and source locations using data from the IMS stations (Li and Gavrilov, HYDRO-14/H). This has been accomplished through the modelling and analysis of the transient signals received by the stations from known ice and iceberg events. Locations of iceshelf and iceberg break-up were determined by satellite images. Using signals generated by selected long-lasting Antarctic ice tremor events, they concluded that the uncertainty of the observed direction of signal arrivals is only 0.2 degrees for IMS receivers at H01 and H08.

SYNERGIES WITH OTHER TECHNOLOGIES

The overlapping coverage between the hydroacoustic and the seismic IMS network was also addressed during ISS09 (Prior et al., HYDRO-07/H). This overlap may enhance localization accuracy, improve knowledge about the event or fill in gaps in coverage by a single network.

Figure 2 shows the location of an event offshore from Carnarvon, Western Australia, which was detected by H08 and H01 on 10 November 2008. The signal was identified by the automatic data processing system implemented at the IDC. The spectrogram of the received signal at both stations strongly suggests that the source of the signal was an in-water explosion (see Figure 3).

The azimuths and times of the signals arriving at H08 and H01 determined a location for this event. However, this in-water event near the coast was recorded at seismic IMS stations in the Australian continent as well. Using signals from both IMS networks, the event was calculated as being located at 25.35 S, 112.13 E with an error ellipse smaller than 10 km². This small uncertainty in location is significantly less than the error ellipses resulting from exclusively processing single network signals.

This in-water event was also detected independently by the Geoscience Australia Seismic network. Locations derived by the IMS are within 20 km of the values of this local Australian network.

Another aspect to the sharing of seismic and hydroacoustic data was presented at ISS09 (Jepsen et al., HYDRO-06/H). In-water, on-island and low-altitude explosions often either contain high-frequency energy (as well as low-frequency energy) or have a short duration. In contrast, earthquakes, which are commonly observed by the hydroacoustic network, typically have a long duration and exhibit mostly low frequency energy (see Figure 1). This difference in frequency content is a clear distinguishing feature between explosions and natural earthquake sources. These features can be used during “event screening”,...
the process which screens out events considered to be consistent with natural phenomena or non-nuclear, man-made phenomena and can provide a pre-classification of events listed in the IDC’s Reviewed Events Bulletin (REB).

**POTENTIAL CIVIL AND SCIENTIFIC APPLICATIONS OF HYDROACOUSTIC DATA**

Signals from numerous sources are observed at hydroacoustic stations. Signatures range from whale vocalizations and ship noise that are seen locally, to ice-calving, earthquakes and explosions that can be observed on an ocean wide scale.

Different posters at ISS09 presented work related to marine mammal monitoring using data received at IMS hydroacoustic stations (Harris et al., HYDRO-12/H; Flore et al., HYDRO-17/H). The population status of many whale species is sparse and difficult to obtain due to their wide-ranging distribution, extensive migration, difficult visual identification, and inaccessibility.

However, large whales produce specific low frequency, high intensity sounds year-long. Three previously described blue whale call types as well as fin whale calls have been identified in IMS hydroacoustic data.

Using passive acoustic monitoring of animals vocalizations to assess whale populations has several benefits in comparison with visual surveys. The animals can be studied continuously without any negative impact. This method is also less dependent on weather conditions than visual methods and does not rely on animals surfacing in order to be detected. It can be applied globally, including remote areas where whale studies are difficult but essential.

To carry out this kind of research, algorithms for automatic whale call detection, extraction and discrimination have been developed and used on IMS hydroacoustic data. Whale monitoring and monitoring nuclear explosions require similar techniques in some areas – in this case for detection. This is an example of how both sides – the CTBTO as well as the scientific community – benefit from close cooperation.

At ISS09 results were presented on the use of hydroacoustic data for tsunami warning purposes (Salzberg, HYDRO-16/H), which had been investigated over the last few years. For example, using data recorded at H08 (see Figure 4) it was shown that those earthquakes that produce significant tsunami released energy of 60 Hertz (Hz) and above. This reveals, for example, the comparison of spectrograms from the two largest earthquakes that have occurred over the last 40 years: the Sumatra-Andaman Earthquake in December 2004 and the Nias Island Earthquake in 2005. The Moment Magnitude “Mw” (used to measure the size of earthquakes in terms of the energy released) for these earthquakes was 9.1 and 8.7 respectively.

The Sumatra-Andaman Earthquake generated a devastating tsunami while the Nias Island Earthquake could not generate much tsunami because of shallow water.
HYDROACOUSTICS

22

SCIENCE FOR SECURITY

Figure 4 showing the hydroacoustic network.

It should be added that in the case of the
Sumatra-Andaman Earthquake, hydroacoustic
data from H08 allowed tracking of the propagating
rupture. This was already shown independently by
the CTBTO and academia in 2005.

CONCLUSION

The hydroacoustic network complements the other
IMS networks and is of particular significance for
coverage of the southern hemisphere, as outlined
on page 18.

In terms of detecting in-water events, it is
unique. The existing network can most certainly
detect low-yield in-water explosions, as demonst-
rated by the test involving only an estimated 20 kg
of TNT off the coast of Japan. Location and identi-
fication capabilities will improve further with more
available “ground-truth” data and with sophistica-
ted data analysis including better understanding of
wave coupling and wave propagation in 3D media
with temporal variations.

The network also allows for measurements on
a global scale and is therefore potentially of great
value for performing studies investigating global
effects. Providing data to the scientific community
will initiate many different kinds of studies. To
realize their research goals, scientists will develop
approaches and algorithms to solve their detection,
localization and characterization problems, which
could be applied to similar problems at the CTBTO.
Some of these benefits are immediate, like those
mentioned in the second section. In other cases,
benefits may be more long-term and indirect.

BIOGRAPHICAL NOTE

WOLFGANG JANS

joined the Federal Armed Forces Underwater Acoustic
and Marine Geophysics Research Institute (FWG) in
Kiel, Germany, as a physicist in 1994.

Since then he has been involved in sound propagation
modelling and sonar signal processing methods, was a
Scientist-in-Charge for several multinational sea trials,
and is currently responsible for sonar methods and sig-
nal processing for the FWG, now renamed the WTD71-
FWG. He took over the advisory activities in Germany
for CTBT-related hydroacoustic issues in 2005.

BIOGRAPHICAL NOTE

KIYOSHI SUYEHIRO

spent nearly thirty years in the research field of marine
seismology at Tohoku University, Chiba University, Uni-
versity of Tokyo and the Japan Agency for Marine Earth
Science and Technology (JAMSTEC).

He is currently President of the Integrated Ocean
Drilling Program Management International and over-
sees a unique international scientific drilling programme
to study the Earth’s evolution and dynamics. His recent
works include establishing high quality sub-seafloor
geophysical observatories to monitor the internal
working of the Earth.